AN ANCIENT VOLCANO IN THARSIS PROVINCE ; E. D. Scott and L. Wilson, Institute of Environmental Sciences, Lancaster University, Lancaster, LA1 4YQ, U. K. , E.Scott@Lancaster.ac.uk. L.Wilson@Lancaster.ac.uk.

We have found evidence for an ancient volcano within Tharsis Volcanic Province, the proximal parts of which are mainly buried beneath volcanic products from Tharsis Montes and Olympus Mons. The distal parts are expressed as long radial dikes with associated collapse craters.

Two Sets of graben on the flanks of Alba Patera.

There are two distinct sets of graben on the flanks of Alba Patera. Set 1 are approximately circumferential in nature, becoming radial to the north and south of Alba Patera. Current thought [1] is that these graben were produced in response to the extensional stress caused by the loading of the volcano. Set 1 are younger than Alba Patera because they fail to divert channels on the north flanks of the shield. (Viking image f253s04.)

Set 2 are oblique to set 1, implying that they formed under very different stress regimes. The majority are seen on the east flanks of the volcano, with only two to the west of the caldera. The western ones are at an approximate radial distance of 400 km from the center of the caldera. They contain numerous, rimless pit chain craters. The simplest scenario for the formation of these craters involves the release of exsolved volatiles from the top of a stalled dike with subsequent collapse of surface material into the void left behind. *Head & Wilson* [2] suggest a similar mechanism for graben linked pit chain craters on the moon. Work is in progress [3] to assess whether the volumes of these craters are consistent with realistic volatile content in Martian magmas. The trend of the cratered graben is different to the east and west of the caldera. However, they appear to converge at a point - approximately equivalent to 112° W, 22° N - presumably the location of the relict volcanic activity. It is probable that these graben formed in the extensional stress regime induced by the intrusion of dikes which stalled at shallow levels within the crust. It is proposed that the oblique graben of set 2 are visible only in the region of Alba Patera because the volcanic products of the more recent Tharsis volcanoes did not quite cover the distal extent of the set.

It is plausible that the graben of set 2 could be associated with dikes that traveled the 600 km or so from the proposed location within Tharsis. The M^{c}Kensie dike swarm in Canada is around 2,000 km in length [4], possibly intruded from a buffered magma chamber.

Age of the Proposed Activity.

The fact that the two sets follow different directional trends and therefore formed under different regional stress regimes implies that they formed at different times. *Turtle & Melosh* [1] proposed that the tectonic graben formed after the building of the Alba shield was complete. This was concluded using the relationship between the set 1 graben and channels on the northern flanks.

Our examination of Viking Orbiter Images f254s09 and f253s21 support the hypothesis that the volcanic set 2 graben are older than the tectonic graben of set 1. A large pit chain crater at point (650, 466) within image f253s21 has the terracing of the adjacent set 1 graben running through it. If the collapse crater had formed after the set 1 graben, this evidence would have been obliterated during the collapse. At point (430, 1029) of image f254s09 a set 2 graben with pit chain craters disappears 'under' a set 1 graben, the terraces of the tectonic graben cutting straight across the obviously older cratered graben. However, the set 2 graben are younger than the lava flows. In image f254s21, a graben intersects a lava flow at points (45, 212), (273, 324) with no change in morphology of the graben, indicating that the graben was produced in response to dike passing below the solidified lava flow. Alba Patera is Hesperian in age [5], with an absolute age of 1.7 x 10^9 year. The set 2 graben and the intrusive activity to which they are related therefore have a **maximum** age of 1.7 x 10^9 years. This is consistent with the hypothesis that a visible record of the volcanic activity which spawned the dikes, and hence graben of set 2, is buried beneath the Tharsis Montes and Olympus Mons products. Olympus Mons, Ascraeus Mons, Pavonis Mons and Arsia Mons are much younger [5] with respective ages of 0.03, 0.1, 0.3 and 0.7 x 10^9 years.

Feature	Age
Set 1 Graben; Tectonic	1.7 Ga (maximum)
Set 2 Graben; Volcanic	1.7 Ga (maximum)
Earlier Channels and lava flows.	

Size of the Proposed Magma Chamber.

Each dike is intruded in one event from the magma chamber. Dike volumes can be calculated and used to infer the size of the proposed magma chamber. *Head & Wilson* [2] have adapted data from Mastin & Pollard [6] to give, in graphical form, the relationship between the width of a graben and the depth to the top of dike underneath.

Graben A seen in images f254s 41, 43, 46, 48, has a width of 2.3 $\pm$ 0.35 km, extrapolating to a dike whose top is at 1.2 $\pm$ 0.2 km depth. Graben B in images 254s17, 19, 21, 24, has a width of 3.6 $\pm$ 0.3 km, which extrapolates to a dike top 1.8 $\pm$ 0.2 km below the surface.

To calculate the vertical height of the dike, it is assumed that the dike center will be located at the neutral buoyancy level, where the magma density and that of the aggregate country rock are approximately equal [6]. For Mars a neutral buoyancy depth of 11 $\pm$ 2 km, [8] is likely. Dike A, therefore has a half height of 10.8 $\pm$ 1.2 km, whilst that of dike B is 9.2 $\pm$ 2.2 km, extrapolating to full heights of 21.6 $\pm$ 2.4 km and 18.4 $\pm$ 4 .4 km respectively.

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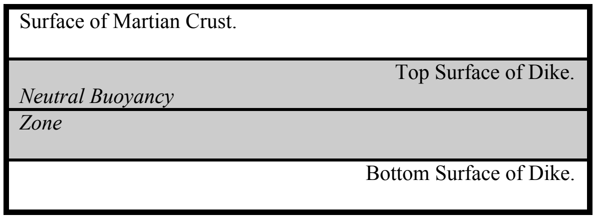

The width of the dike can be calculated using the extension across the graben. If the extension across the graben is e/2 across each boundary fault, the width of the dike initiating that graben is 3e/2. [2]. To calculate the extension, the depth to the floor of the graben is required. This can be calculated using trigonometry and the length of the shadow thrown by the graben wall. The extension across the graben wall is then $e = d \tan 30^0$, assuming a 60^0 slope to the graben boundary fault.

The measured shadow lengths within graben A and B are 265 $\pm$ 70 m and 330 $\pm$ 60 m respectively. Using sun incidence angles for the appropriate images gleaned from the Mars Directory [9] on the world wide web, the depths to the floor of the graben are calculated as $d_A = 105 \pm 28$ m and $d_B = 110 \pm 19$ m. The extension across graben A and B was then calculated to be 61 $\pm$ 16 and 63 $\pm$ 11 m respectively. Using the fact that a dike has a width equivalent to 3/2 times this extension across the graben, the widths of the dikes A & B are 91.5 $\pm$ 24 and 94.5 $\pm$ 16.5 m respectively. These dike widths are greater than would be implied using models of rift zone dikes such as those of *Rubin and Pollard* [10]. The discrepancy may be explained by the physical parameters of the model in which the dike is assumed to stall within brittle rocks. Current models [11] of the Alba Patera circumferential (set 1) graben indicate a vertically extensive ductile substratum. This would mean that a thinner dike intruded within this fabric could take longer to cool and hence be able to travel longer distances. It could also have the consequence that the driving pressure required to overcome the fracture toughness of the host rocks need not be so great if the dike is intruded into a ductile region as opposed to encountering brittle conditions assumed within previous models. The dike would therefore be able to travel further under the influence of a smaller driving pressure.

Using all these calculated parameters for the dikes and an approximate length of 600 km, the volumes of dikes A & B are 610 $\pm$ 220 and 540 $\pm$ 220 km^3 respectively.

Blake [12] calculates that approximately 1% of an *unbuffered* basaltic magma chamber is discharged in each intrusive event. The volumes of these dikes indicate an approximate volume for the ancient magma chamber of 50,000 to 60,000 cubic kilometers. If, however, the magma chamber was *buffered*, as is thought to have been the case during the intrusion of the long M^c^Kensie radial dike swarm in Canada, then much more than this 1% of the chamber could be discharged in one event. The calculated volume would then be a maximum size for the chamber and it could actually be much less than this.

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